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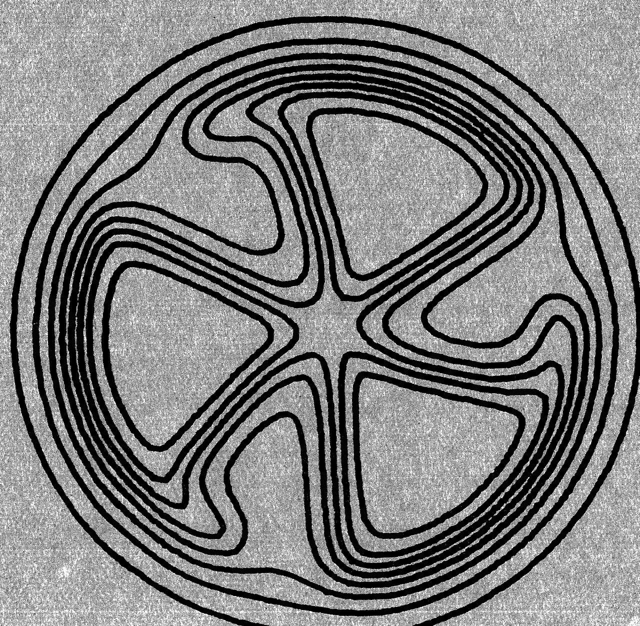

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# Inelastic Proton Scattering from $^{138}Ba$ and $^{144}Sm$ at 30 MeV*

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ABSTRACT

Measurements of the inelastic scattering of 30 MeV protons from $^{138}Ba$ and $^{144}Sm$ have been carried out with better than 10 keV energy resolution. Differential cross sections were measured for levels up through 3.4 MeV excitation energy. Spin and parity assignments are suggested for most of these states on the basis of angular distributions distinctly characteristic of angular momentum transfer L=2,3,4, or 6.

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The stable N=82 nuclei are interesting because they allow one to study the effects of adding from four to twelve valence protons to a doubly closed Z=50,N=82 core. In this note we present results of experiments on $^{138}$Ba (6 valence protons) and $^{144}$Sm (12 valence protons) which show that high resolution inelastic proton scattering in the 30 MeV range is an effective tool for making spin-parity assignments in this mass region as well as for identifying levels and measuring their precise excitation energies.

The present data were taken with the Michigan State University Cyclotron and Enge split-pole spectrograph. Targets, ranging in thickness from 70 to 300 $\mu g/cm^2$, were fabricated by vacuum evaporation of enriched isotopes onto thin carbon foils. Angular distribution measurements for the first $2^+$ and $3^-$ levels and for elastic scattering were made with a position-sensitive detector in the spectrograph focal plane. Photographic emulsions were used to record spectra at 5° intervals from 20° to 80° for $^{138}$Ba and from 12° to 95° for $^{144}$Sm. Cross sections were obtained by normalizing the measured elastic scattering distributions to optical model calculations based on Becchetti-Greenlees[1] parameters and are estimated to be accurate to better than 15%. A spectrum of $^{144}$Sm is shown in Fig. 1. The energy resolution obtained for inelastic groups was usually better than 10 keV, FWHM.

The data at each angle were reduced by using automatic peak fitting routines to extract peak centroids and areas. These centroids were then used to assign excitation energies to all levels excited in $^{138}$Ba and $^{144}$Sm based on the energies of a known subset of levels in these nuclei; the results are shown in Table I.

The considerable information about the low-lying levels of $^{138}$Ba available from $(n,\gamma)$,[2] $(d,{}^{3}He)$[3] and $(\beta,\gamma)$[4] experiments has been summarized by Hill and Fuller.[4] The present results for $^{138}$Ba are in almost complete agreement with this summary as regards number of levels excited in the 0-2.9 MeV range and their precise energies. Further, the angular distributions for the more strongly excited states of known $J^{\pi}$ can be classified into distinctive groups characterized by the L-transfer involved. Characteristic shapes for L=2,3,4,6 were obtained by averaging over the appropriate groups of angular distributions, and are compared to each other in Fig. 2. Also shown in Fig. 2 are the angular distributions for the lowest lying states in $^{138}$Ba, with the appropriate characteristic curves drawn through them. Each of the remaining states in $^{138}$Ba that exhibited one of these characteristic shapes was assigned $J^{\pi}$ on this basis, and the assignments, shown in Table I, are generally consistent with the conclusions of Hill and Fuller.

The results just discussed for $^{138}$Ba give us confidence that 1) high resolution 30 MeV (p,p') scattering will excite essentially all low-lying levels (with the exception perhaps of $0^+$ states) with measurable intensity and 2) the (p,p') angular distributions are good indices of transferred L, and hence of the $J^\pi$ of the more strongly excited natural parity states.

We have analyzed our $^{144}$Sm data in the light of our results for $^{138}$Ba. The results for level excitation energies, listed in Table I, identify many previously unknown levels in $^{144}$Sm. A comparison of their angular distributions with the standard shapes, as shown in Fig. 2, was used to establish the $J^\pi$ of the more strongly excited levels the new $^{144}$Sm spin-parity assignments are also listed in Table I.

A comparison of the present results with theoretical expectations for these nuclei yields a further estimate of the completeı of the energy level spectra obtained and of the accuracy of the $J^\pi$ assignments. An energy level scheme for $^{140}$Ce calculated in the shell model[6] accurately accounts for the known positive parity levels of that nucleus up to 3 MeV excitation, without duplication. Comparison of the observed level schemes of $^{138}$Ba and $^{144}$Sm with similar calculations[7] indicates that all but two (three) of the states predicted to lie below 3 MeV in $^{138}$Ba ($^{144}$Sm) can be tentatively correlated with observed levels. Four of the unobserved levels have unnatural parity and are expected to be very weakly populated. Furthermore, all observed levels to which we assign J and positive parity can be put in one-to-one correspondence with model states.

We express our appreciation to S.H. Fox for his assistance in making the measurements, and to S. Raman for communicating $^{144}Sm$ results prior to publication.

Table I

Energy Levels of $^{138}$Ba and $^{144}$Sm

| $^{138}$Ba | | | | $^{144}$Sm | | | |
|---|---|---|---|---|---|---|---|
| Present Work $E_x[J^\pi]$[a,d] | | Previous Work $E_x[J^\pi]$[b] | | Present Work $E_x[J^\pi]$[a,d] | | Previous Work $E_x[J^\pi]$[c,f] | |
| 1436 | $2^+$ | 1435.7 | $2^+$ | 1661* | $2^+$ | 1660.6 | $2^+$ |
| 1898* | $4^+$ | 1898.4 | $4^+$ | 1811 | $3^-$ | 1810.1 | $3^-$ |
| 2090* | $6^+$ | 2090.1 | $(6)^+$ | 2191* | $4^+$ | 2190.6 | $4^+$ |
| 2201 | | | | 2324[e] | | 2323.2 | $6^+$ |
| 2218 | $2^+$ | 2217.9 | 2 | 2423* | $2^+$ | 2423.4 | |
| 2308* | $4^+$ | 2307.4 | (3,4) | 2478 | | 2478.3 | $0^+$ |
| 2415 | | 2414.9 | (4,5) | 2588 | $4^+$ | | |
| 2445 | | 2445.4 | (3,4) | 2661 | | | |
| 2584 | $4^+$ | 2582.8 | 1,2 | 2800 | $2^+$ | | |
| 2639 | $2^+$ | 2639.3 | 2 | 2826 | | 2830 | |
| 2779* | $4^+$ | 2779.2 | 2,3,4 | 2883 | $4^+$ | | |
| 2881 | $3^-$ | 2880.5 | $3^-$ | 3020 | $4^+$ | | |
| (2929) | | 2931.1 | 1,2 | 3080 | | | |
| (2990) | | 2990.8 | 1,2,3,4 | 3123 | | 3123.8 | |
| 3050* | | 3049.9 | 1,2 | 3196 | | | |
| 3156 | $4^+$ | 3163.5 | 2,3,4 | 3227 | $3^-$ | | |
| 3254 | | | | 3266 | | | |
| 3285 | | | | 3308 | $6^+$ | | |
| 3339 | $2^+$ | 3339.5 | 1,2 | | | | |
| 3368 | $2^+$ | 3352.2 | 1,2 | | | | |
| | | 3365.9 | 1,2 | | | | |

[a]Excitation energies in keV. Uncertainties are ±2 keV.

[b]From Ref. 4.

[c]From Ref. 5 and references cited therein.

[d]Subset of levels used in energy calibrations is marked with an asterisk (*).

[e]Unresolved doublet whose angular distribution is consistent with a spin $6^+$ state plus a lower spin state.

[f]S. Raman, private communication.

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## FIGURE CAPTIONS

Figure 1. Spectrum from $^{144}$Sm(p,p') at 40°. The resolution is about 7 keV. The broad bumps under certain of the peaks correspond to protons which scatter from $^{24}$Mg and $^{28}$Si impurities and hence lie on a different focal plane in the spectrograph. The $3^-$ peak at 1811 keV was too intense to be counted on this plate.

Figure 2. Angular distributions for $^{138}$Ba and $^{144}$Sm. The curves through the data are the characteristic shapes. Excitation energies are in MeV.

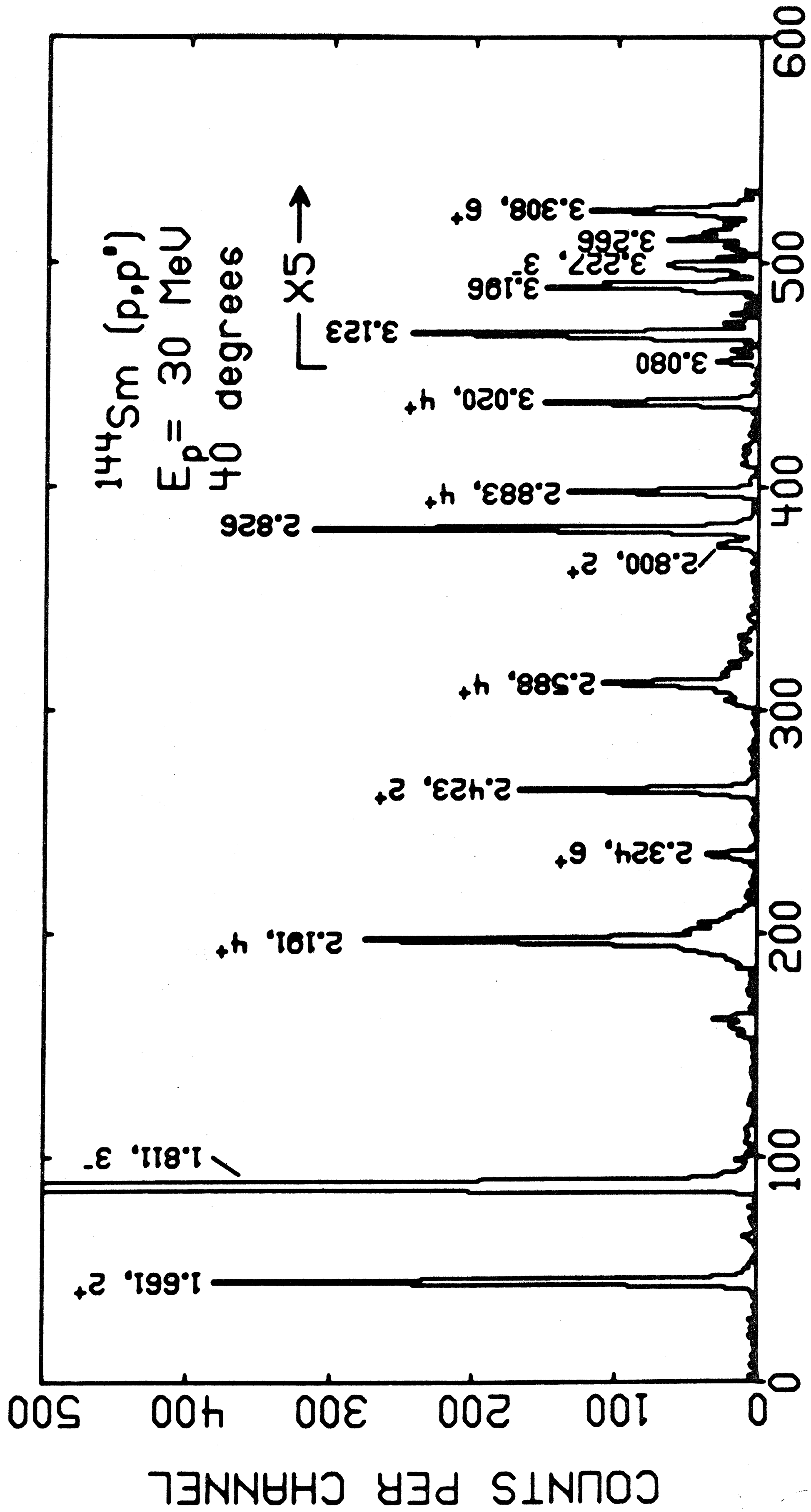
144Sm (p,p')
Ep = 30 MeV
40 degrees
X5
1.661, 2+
1.811, 3-
2.191, 4+
2.324, 6+
2.423, 2+
2.588, 4+
2.800, 2+
2.826
2.883, 4+
3.020, 4+
3.080
3.123
3.196
3.227, 3-
3.266
3.308, 6+
0
100
200
300
400
500
600
CHANNEL NUMBER
COUNTS PER CHANNEL

Figure 1

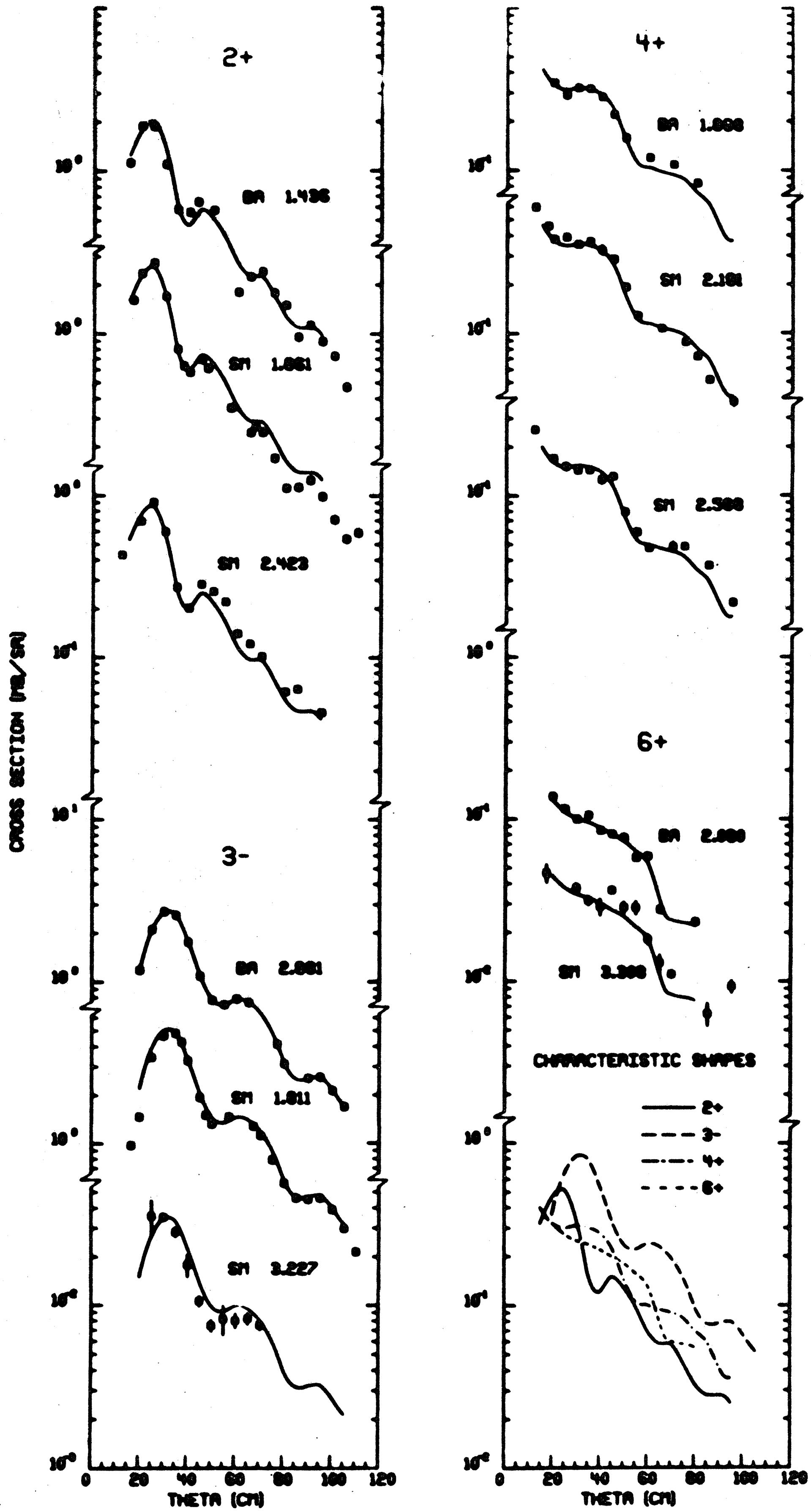
2+
BA 1.436
SM 1.861
SM 2.423
3-
BA 2.881
SM 1.811
SM 3.227
4+
BA 1.898
SM 2.181
SM 2.388
6+
BA 2.888
SM 3.388
CHARACTERISTIC SHAPES
2+
3-
4+
6+
CROSS SECTION (MB/SR)
THETA (CM)
THETA (CM)

Figure 2